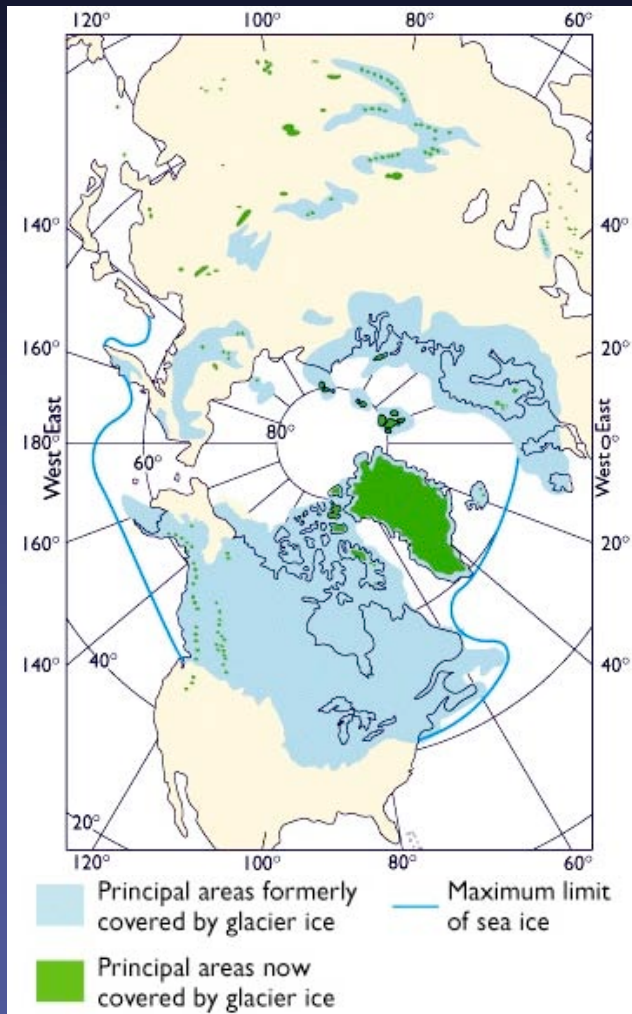




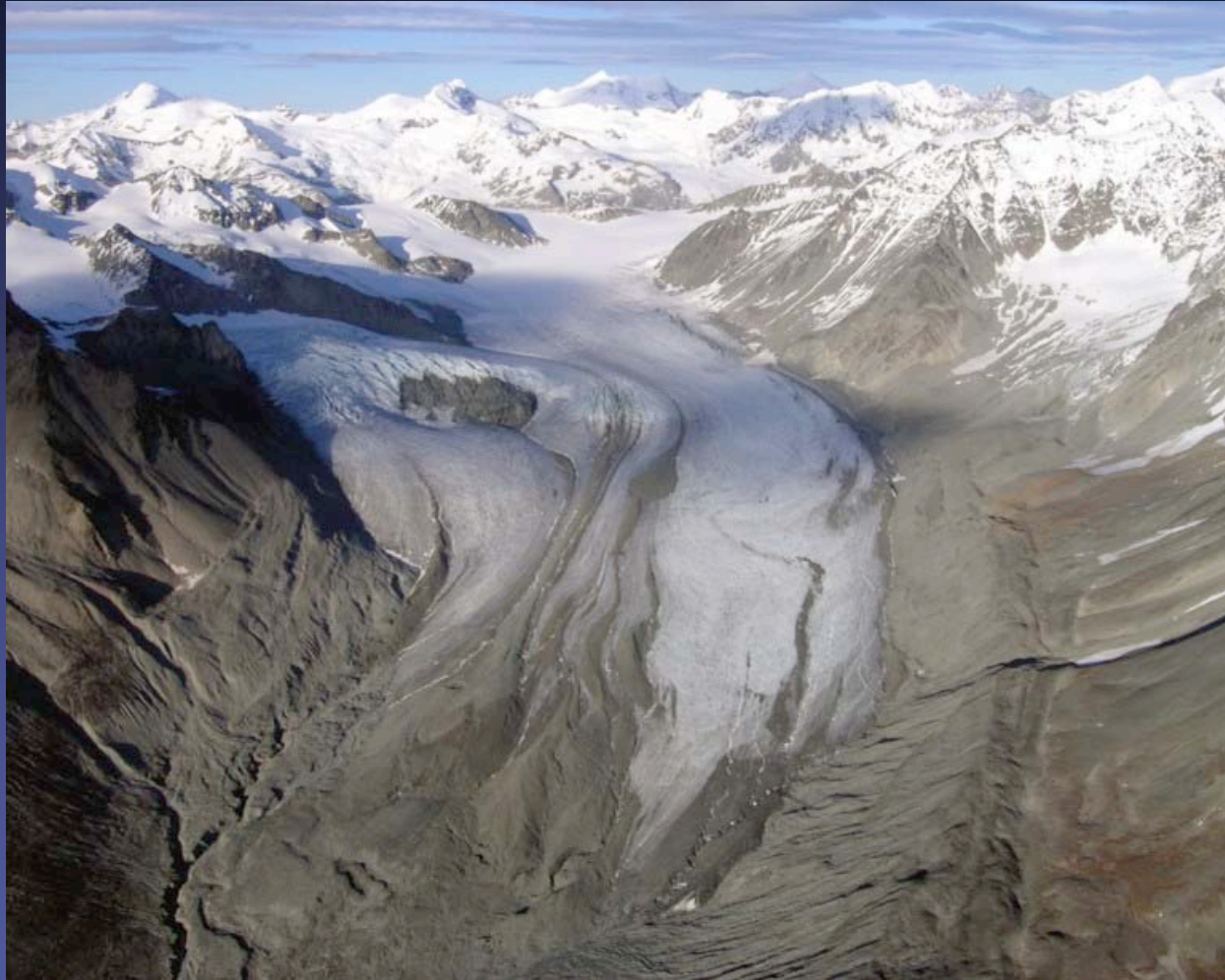
## The Ice Age: 2. Milankovitch Cycles & Climate Change

# Glaciation in the northern hemisphere

(correction from last time: The ice-free corridor is no longer regarded as the route man took into North America.)



# A receding glacier: Gulkana Glacier, AK



# Glacial recession

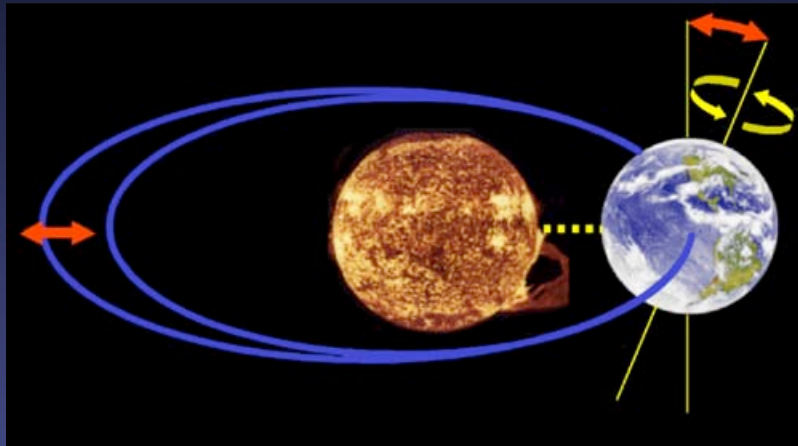


Gulkana Glacier

South Cascade  
Glacier in 1928  
and 2000

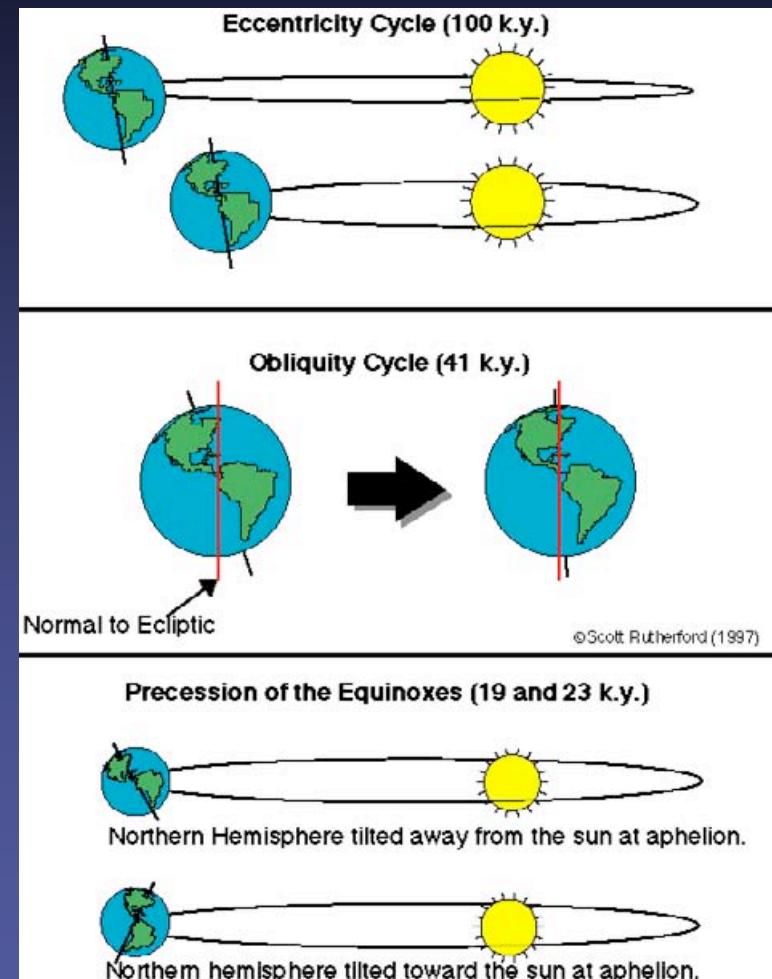


# Why do glaciers advance and retreat? Milankovitch Cycles

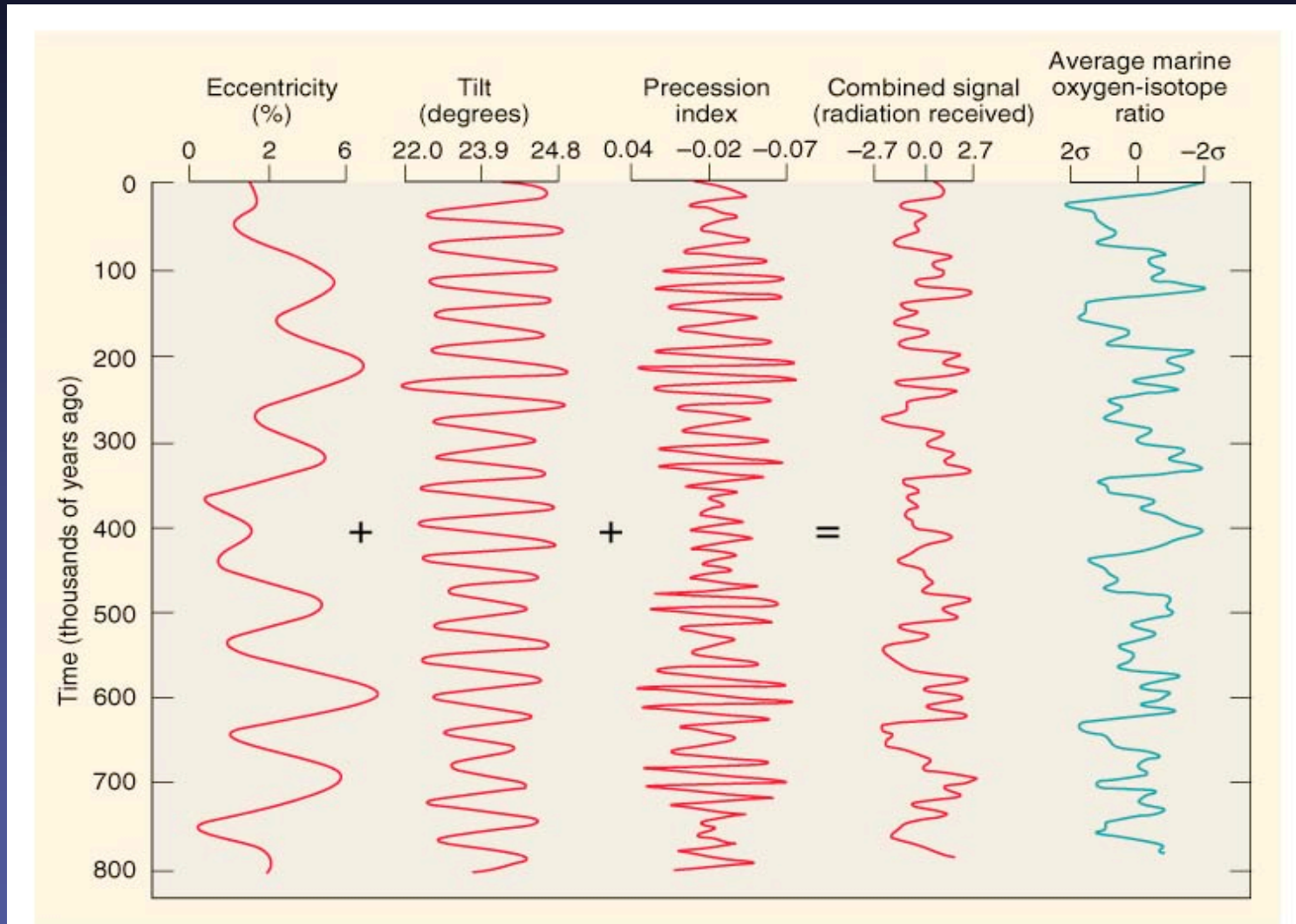


Three systematic variations in the Earth's motion. Discovered by Milutin Milankovitch:

- Variation in the eccentricity of the orbit
- Variation in the tilt of the Earth
- Nutation (precession of the equinoxes)

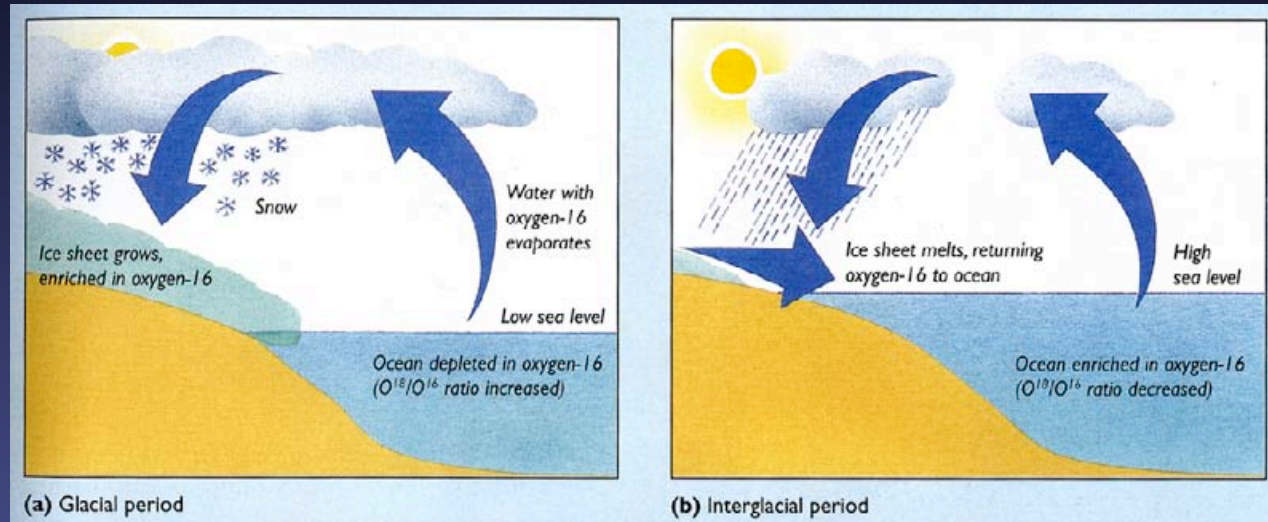


# Do Milankovitch Cycles work? Yes.



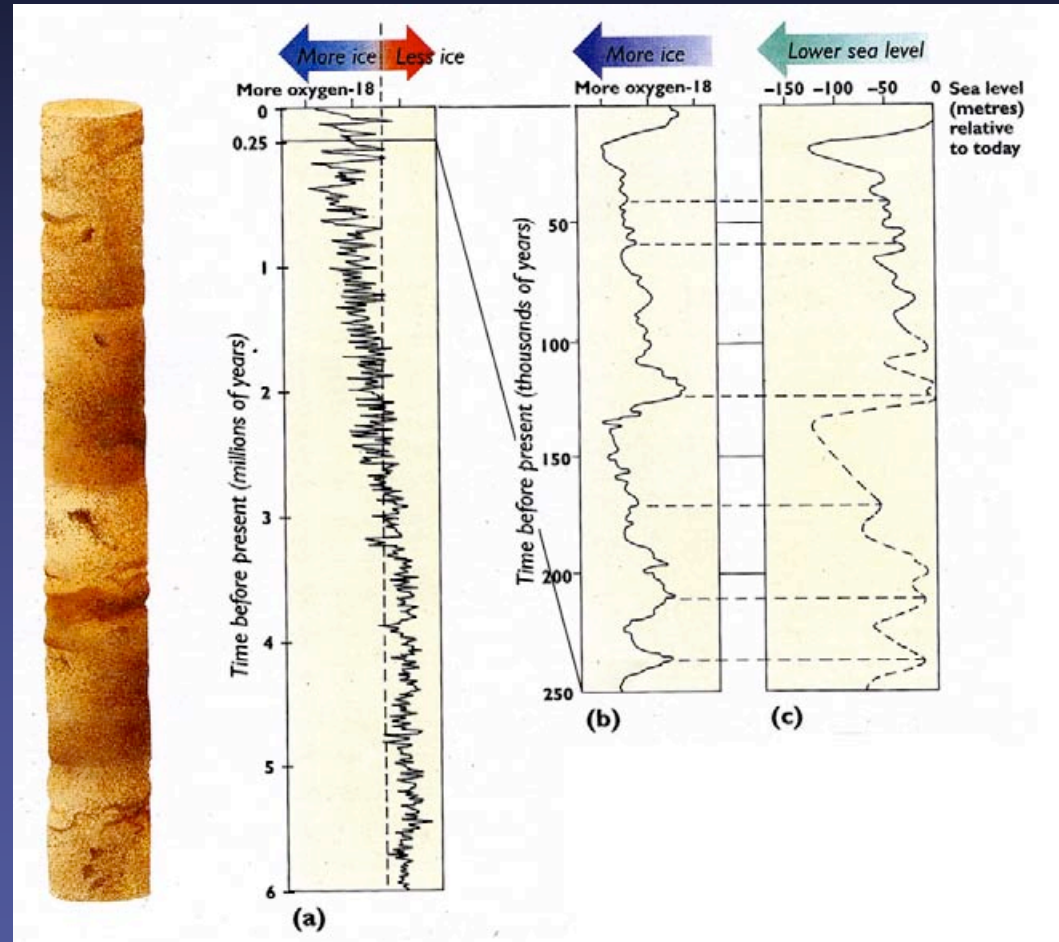
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# $O^{16}/O^{18}$ ratio



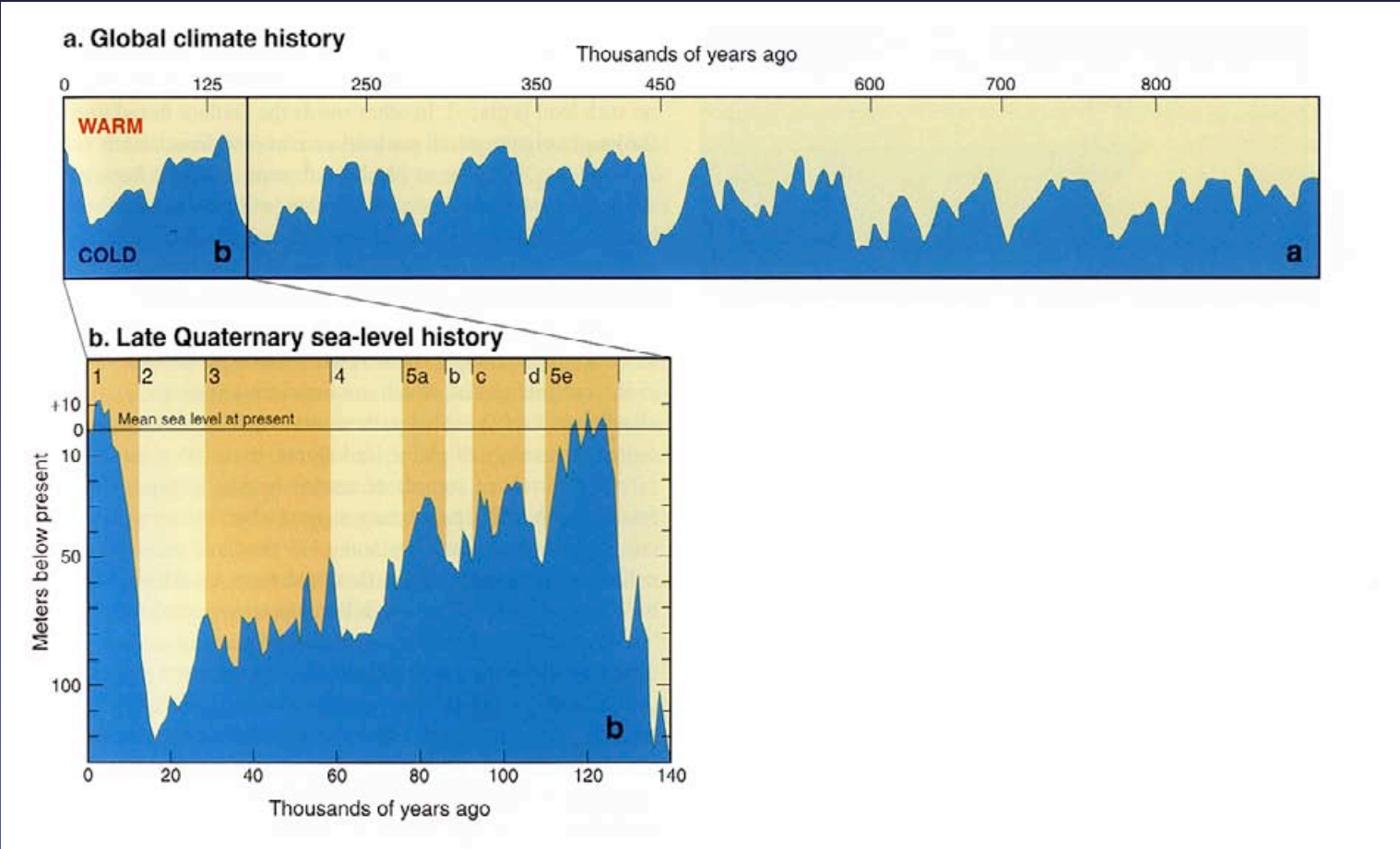
- Oxygen has two stable isotopes,  $O^{16}$  and  $O^{18}$ .
- $O^{16}$ , with two neutrons fewer than  $O^{18}$ , is slightly lighter.
- Water ( $H_2O$ ) with light oxygen evaporates *slightly* more readily from the ocean than water with heavy oxygen.
- Snowfall is therefore enriched in  $O^{16}$  relative to the ocean.
- As glaciers grow, the ocean is progressively depleted in  $O^{16}$ .
- As the  $O^{16}/O^{18}$  ratio in the ocean is reduced, the  $O^{16}/O^{18}$  ratio in the latest snow is also reduced.
- So the  $O^{16}/O^{18}$  ratio is directly related to sea level and to temperature.

# Isotope record in deep sea core





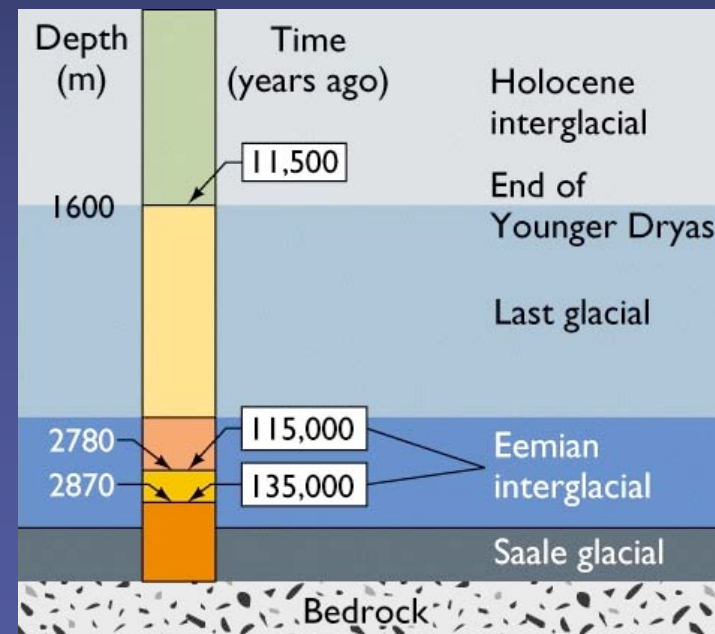
# Sea level variations



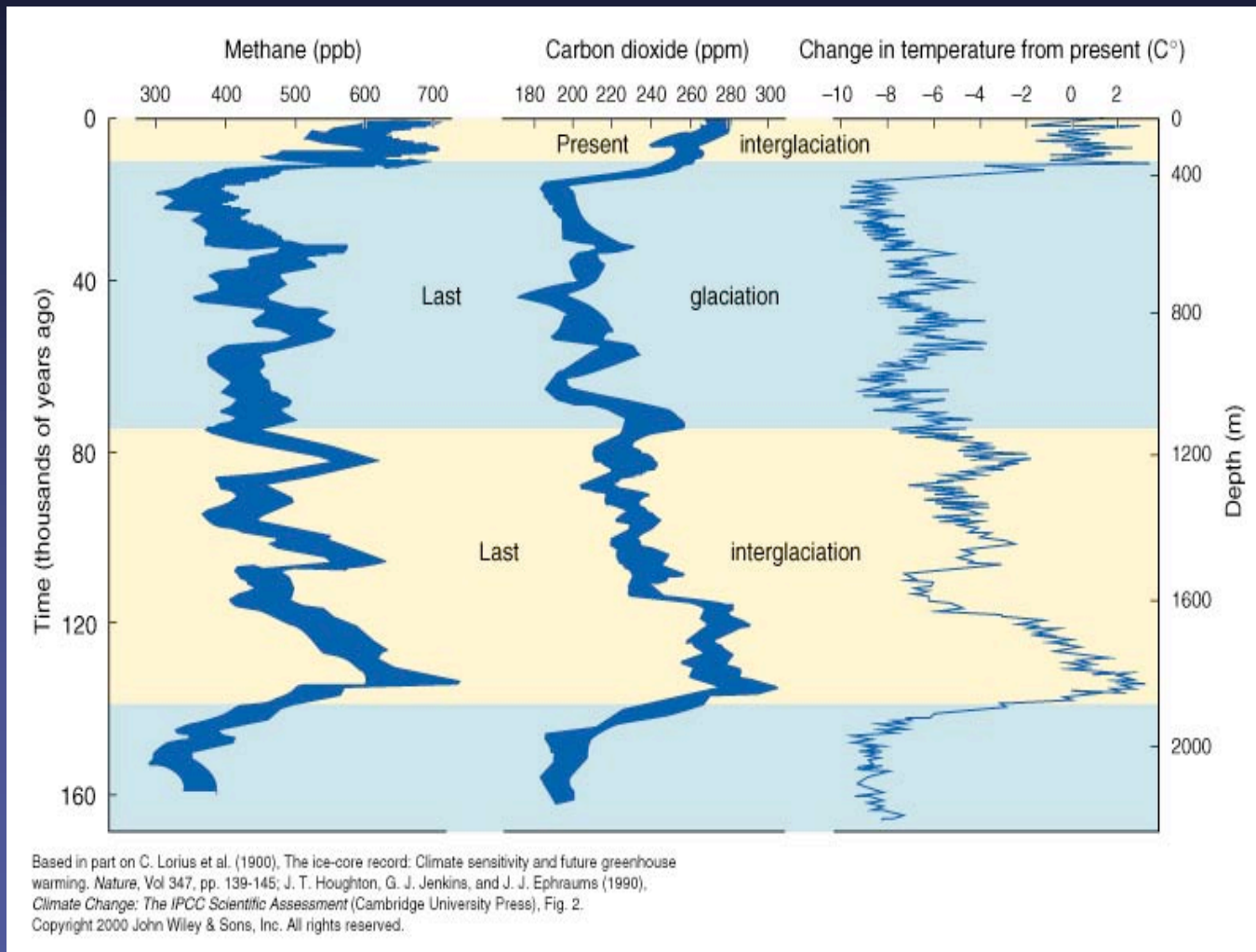


## Ice cores from Vostok Station, Antarctica

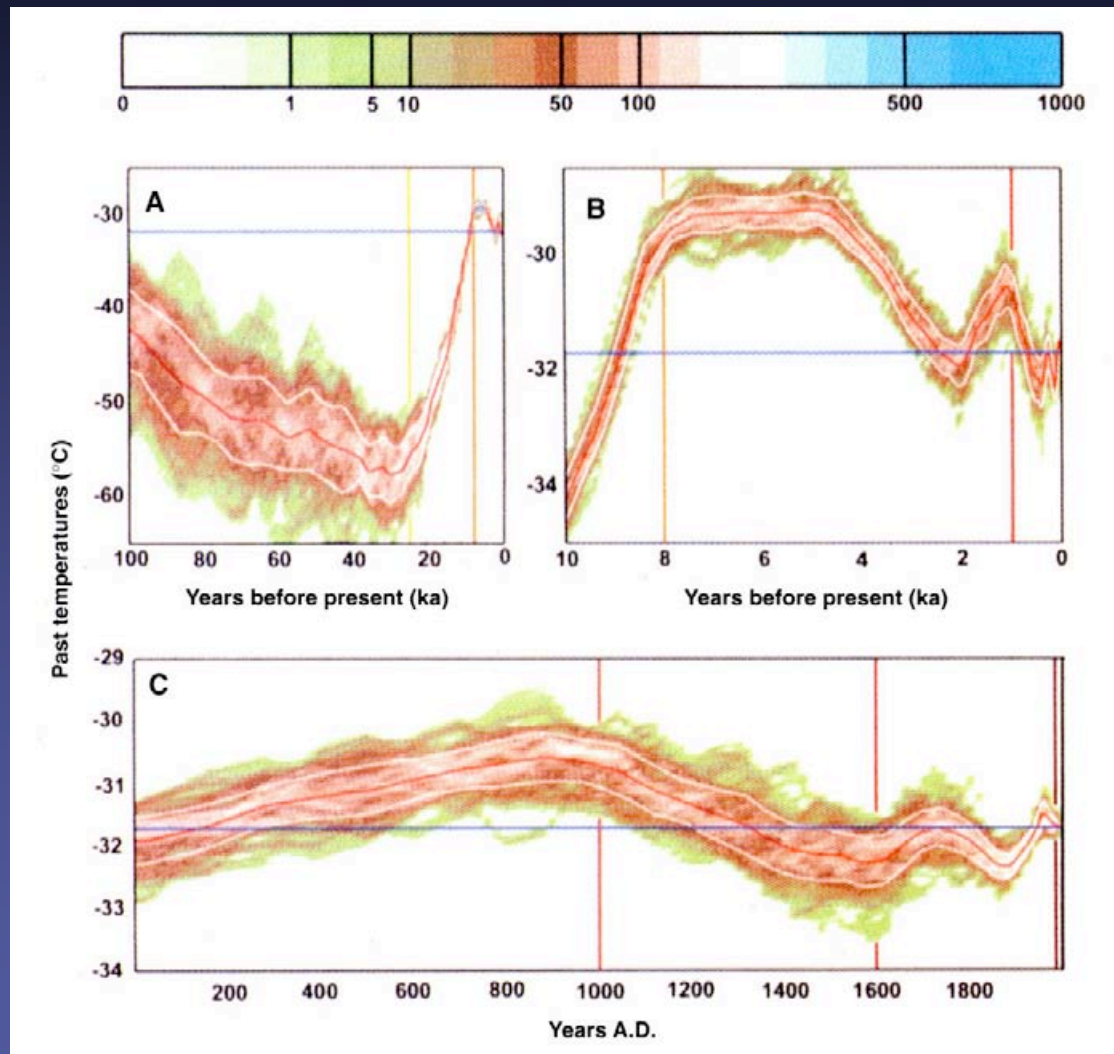
(The Greenland core now goes back even farther, to 250,000 years)



# Vostok

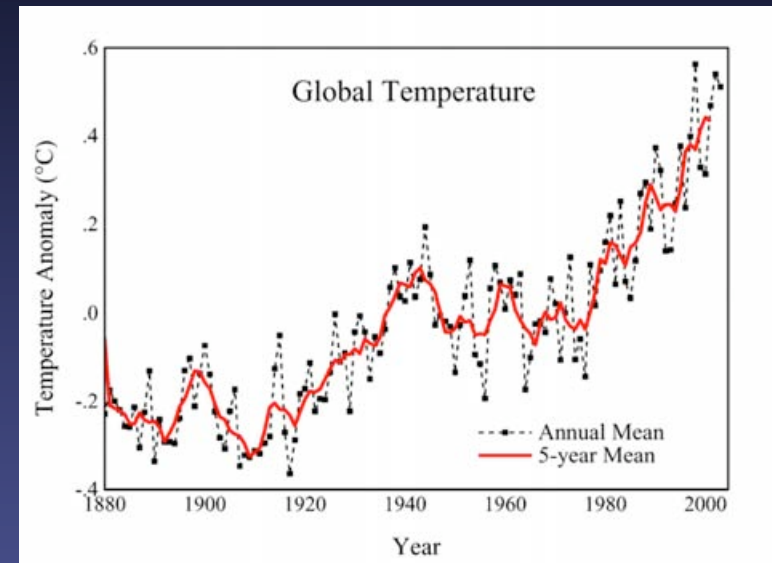
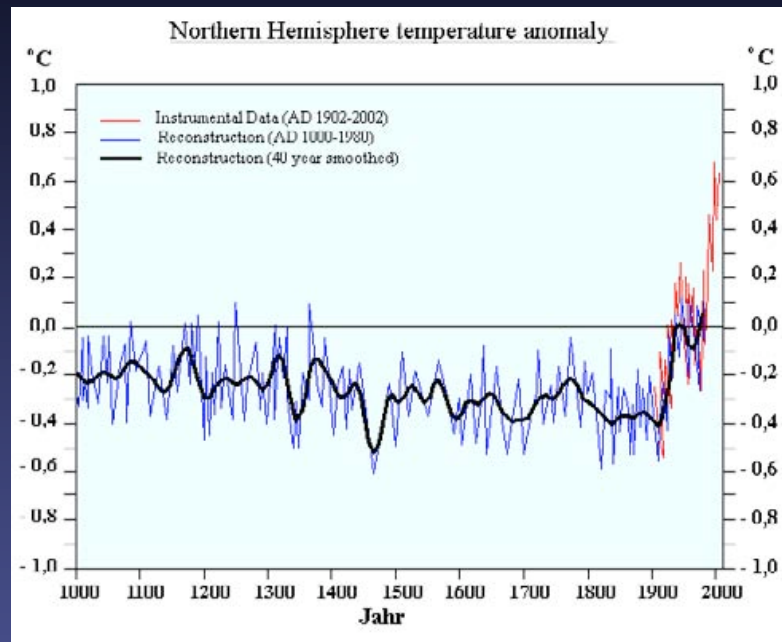


# Temperatures from the Greenland Ice Core



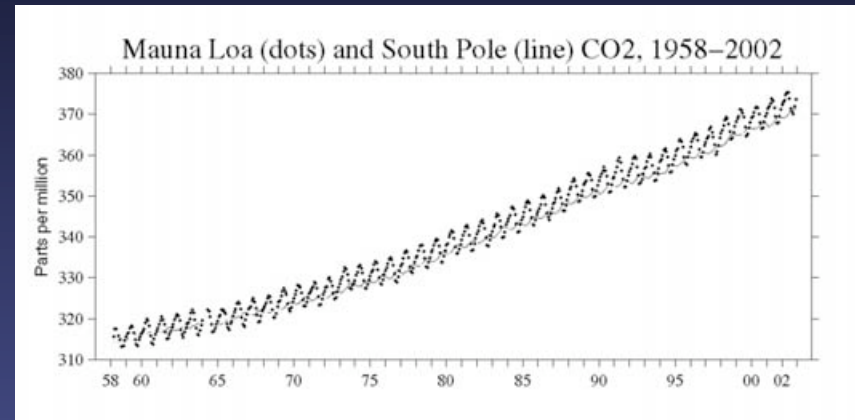
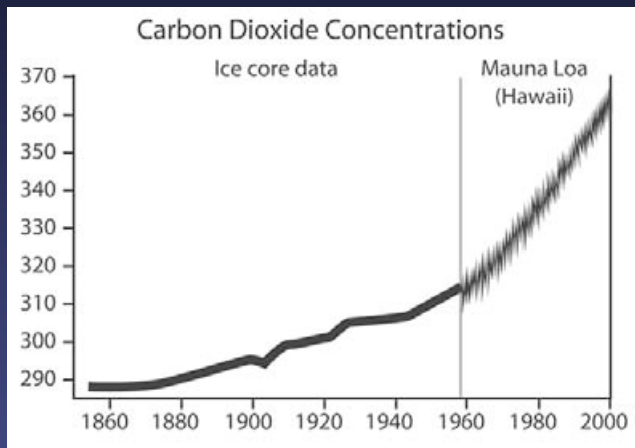
“ka” means  
“thousands of years  
before present”  
  
 (“Ma” means  
“millions of years  
before present”)

## Recent temperature changes



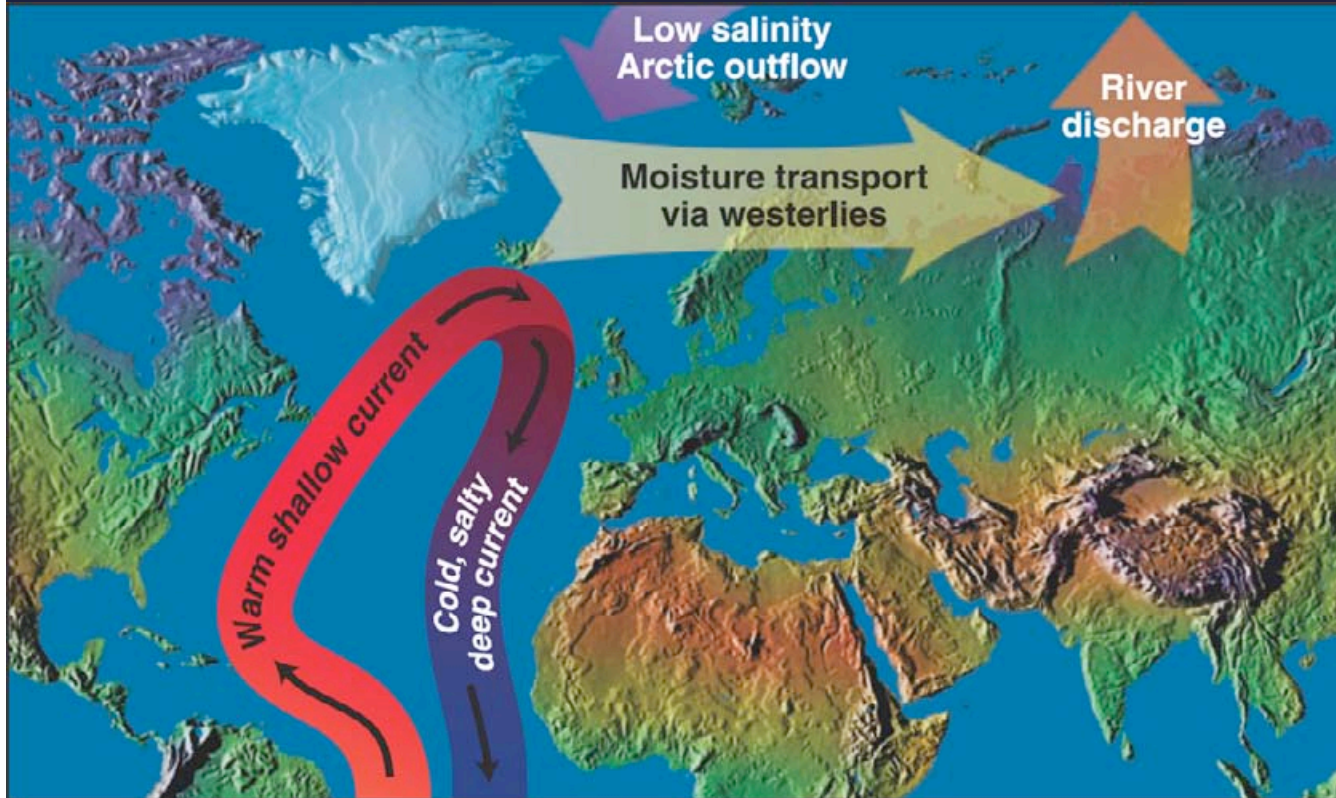
- We know in pretty good detail how Earth pulled itself out of the latest Ice Age, but we have no idea how rapidly an Ice Age can begin.

# Why the recent temperature change?



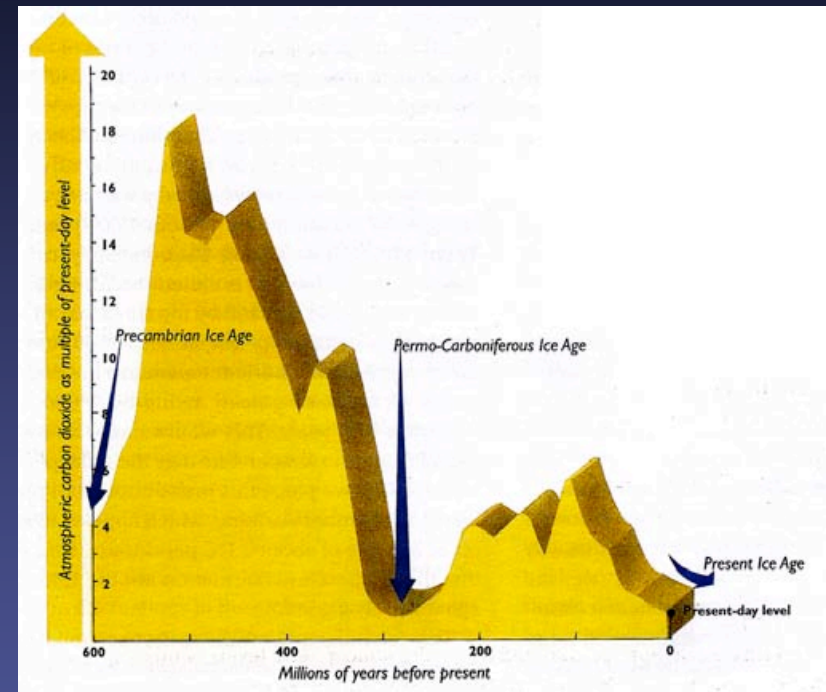
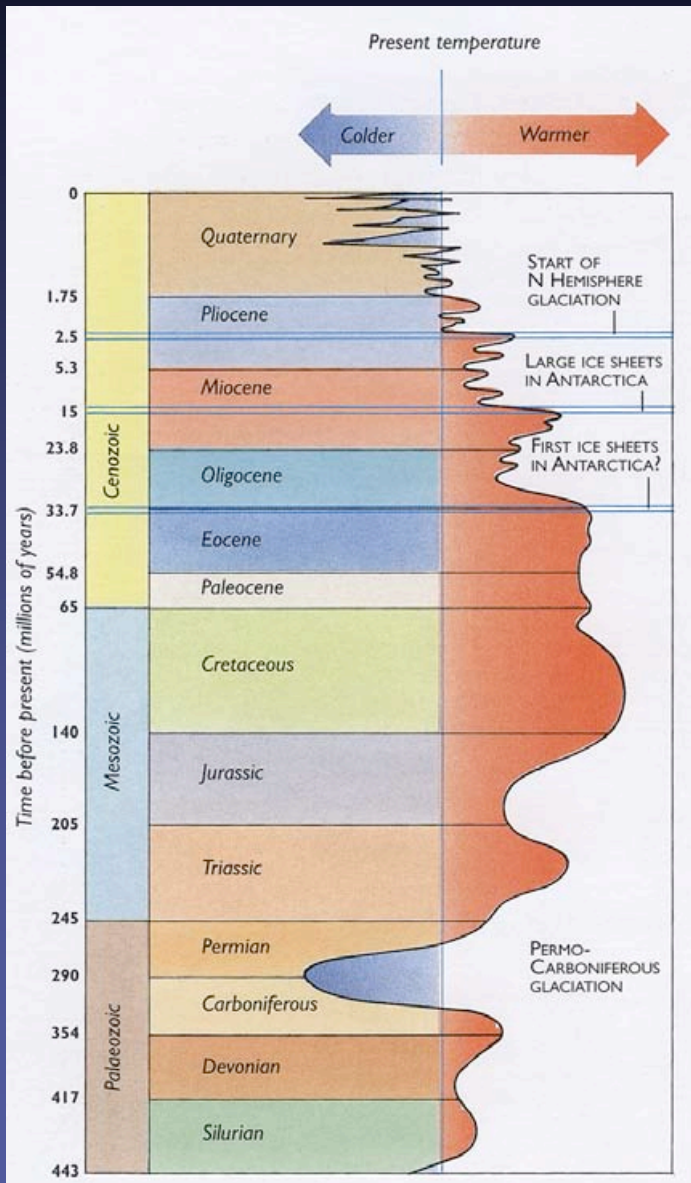
- CO<sub>2</sub> concentration in the atmosphere definitely plays a role.
- The human contribution is important and has contributed to warming,
- Warming was, however, inevitable.
- The problem is the *rate* of warming.

# The consequence of global warming: a new ice age?



- Melt ice, increase rainfall.
- Cold fresh water stops the warm current.
- Europe gets much colder.
- We enter an Ice Age!
- Could happen fast (75 years), but not as fast as *The Day After Tomorrow*.

# Very long term temperature variations



- The Permo-Carboniferous Ice Age was probably caused by the ascendance of land plants.
  - CO<sub>2</sub> taken out of the atmosphere and locked up in carbonates.
- The modern Ice Age may be related to mountain building.